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INVESTIGATION OF F-111 CREW MODULE STABILIZATION PARACHUTE MODELS AT MACH NUMBERS OF 0.5, 2.0, 2.2, AND 2.5 PHASE I

Lawrence L. Galigher
ARO, Inc.

April 1965

PROPULSION WIND TUNNEL FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

INVESTIGATION OF F-111 CREW MODULE STABILIZATION PARACHUTE MODELS AT MACH NUMBERS OF 0.5, 2.0, 2.2, AND 2.5 PHASE I

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FOREWORD

The work reported herein was done at the request of the Aeronautical Systems Division (ASD), Air Force Systems Command (AFSC), for the McDonnell Aircraft Corporation under Program Element 33420014/324A.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1000. The test was conducted from February 1 to 12, 1965 under ARO Project Number PS0536, and the report was submitted by the author on March 31, 1965.

This technical report has been reviewed and is approved.

Francis M. Williams
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ABSTRACT

A test was conducted in the Propulsion Wind Tunnel, Supersonic (16S) to obtain drag, stability, and inflation characteristics of full-scale and quarter-scale models of proposed stabilization parachute configurations for the F-111 airplane crew module. The parachutes were fabric, ribbon-type models of the hemisflo family of parachutes with geometric porosities of the canopy of 15, 18, and 21 percent. The parachute characteristics were investigated at nominal Mach numbers of 0.5, 2.0, 2.2, and 2.5 at a nominal free-stream dynamic pressure of 120 psfa. Test results indicate that the drag coefficient of the full-scale and quarter-scale parachutes decreases as supersonic Mach number increases and that the stability of a quarter-scale parachute is better than the stability of a full-scale parachute for the same riser line length.

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TABLE

NOMENCLATURE

C_{D_O}	Parachute drag coefficient, $\frac{F_D}{q_\infty S_O}$
F_D	Parachute drag force, lb
M_∞	Free-stream Mach number
q_∞	Free-stream dynamic pressure, psfa
Re/ℓ	Reynolds number per unit length
r	Ratio of full-scale parachute drag coefficient to quarter-scale parachute drag coefficient
S_O	Parachute canopy surface area a. 28.27440 ft^2, full-scale parachute b. 1.76715 ft^2, quarter-scale parachute

SECTION I
INTRODUCTION

A three-phase test program was initiated in the Propulsion Wind Tunnel, Supersonic (16S) to establish a stabilization parachute configuration which would provide adequate steady-state longitudinal and lateral-directional stability for the F-111 Crew Module. The purpose of the Phase I test, reported herein, was to obtain drag, stability, and inflation characteristics of full-scale and quarter-scale models of the proposed stabilization parachutes for the F-111 Crew Module and to determine if scale effects were evident between the full-scale and quarter-scale parachute models. The results of the Phase I test will be used to select a quarter-scale parachute model which has a drag coefficient variation most nearly approximating the values of the full-scale parachute. The quarter-scale parachute selected will be used during the two subsequent test phases.

The parachutes investigated during this test were fabric, ribbon-type models of the hemisflo family of parachutes. The parachutes were tested at nominal Mach numbers of 0.5, 2.0, 2.2, and 2.5 at a nominal free-stream dynamic pressure of 120 psfa.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16S is a closed-circuit, continuous flow wind tunnel currently capable of operating at Mach numbers from 1.65 to 3.20. Subsonic Mach numbers from 0.35 to 0.60 can be established by setting the nozzle contour for Mach 1.5 and using the variable geometry diffuser to establish sonic flow conditions downstream of the test section. The tunnel is capable of operating over a stagnation pressure range from 100 to approximately 1800 psfa. The test section stagnation temperature can be controlled through the range of 100 to 650°F. The wind tunnel specific humidity is controlled by removing tunnel air and supplying conditioned make-up air from an atmospheric dryer. A complete description of the facility and its operating characteristics are contained in Ref. 1.

2.2 TEST ARTICLE

2.2.1 Model Centerbody and Deployment System

The parachutes tested during this investigation were deployed from strut-mounted centerbodies. Dimensions of the full-scale and quarter-scale model centerbodies are presented in Figs. 1a and b, respectively. The locations of the full-scale and quarter-scale model centerbodies in the wind tunnel are shown in Figs. 2a and b, respectively. The wind tunnel installation of the full-scale model centerbody is shown in Fig. 3. The quarter-scale model centerbody with a deployed parachute is shown in Fig. 4.

The full-scale and quarter-scale parachutes were packed in the aft end of the respective centerbodies on a spring-loaded plate. The full-scale parachute was held against the plate by retaining straps, and the quarter-scale parachute was held against the plate by electrical conducting wire. The retaining straps were released by a squib-fired release pin mechanism, and the electrical conducting wire was burned apart by applying a 110-v alternating current to the wire. A three-quarter rear view of a full-scale parachute packed in the aft end of the centerbody is shown in Fig. 5. The parachute riser line was affixed to the full-scale and quarter-scale model centerbodies by a swivel-cable-load link combination. The purpose of the swivel was to prevent twisting of the parachute suspension lines. A shear pin, designed to protect the load link, connected the parachute riser line to the swivel.

2.2.2 Stabilization Parachutes

The full-scale and quarter-scale hemisflo parachutes were constructed of 2- and 0.5-in.-wide nylon ribbons, respectively. The nylon ribbons for both the full-scale and quarter-scale parachutes were of the same nylon material. No attempt was made to scale the nylon fibers for the quarter-scale parachutes. The riser and suspension lines were also of nylon construction. The hemisflo parachute configurations are identified by nominal diameter and geometric porosity. Nominal diameter is defined as the diameter of a circle having the same area as the total area of the drag-producing surface, which includes all openings in the drag-producing surface, such as slots and vents. Geometric porosity is defined as the ratio of the open area of a drag-producing surface to the total drag-producing surface area. The full-scale parachutes had a nominal diameter of 6 ft and a suspension line length (skirt to confluence point) of 12 ft. The quarter-scale parachutes had a nominal diameter of 1.5 ft and a suspension line length of 3 ft. However, the riser line length was not scaled and was 5.75 ft for both the full-scale and quarter-scale parachutes. The full-scale and quarter-scale parachutes had porosities of 15, 18, and 21 percent. Details of the full-scale and quarter-scale parachutes are shown in Figs. 6a and b, respectively. The relative size of a full-scale and a quarter-scale parachute is shown in Fig. 7.

2.3 INSTRUMENTATION

A 5000-lb capacity, double element load cell and a 250-lb capacity, single element load flexure were used to measure the drag load of the full-scale and quarter-scale parachutes, respectively. A direct-writing oscillograph was used to monitor the parachute drag load during testing. Five movie cameras were installed throughout the test section to provide visual parachute data, and two television cameras were used to monitor the parachute during testing.

SECTION III
PROCEDURE

A parachute was packed in the aft end of the strut-mounted centerbody before initiation of wind tunnel test operations. Once test conditions were established, the parachute was ejected into the airstream by the spring-loaded plate. Motion pictures and dynamic drag data were obtained during and after each deployment. Upon completion of the parachute deployment sequence, a steady-state drag load was calculated by averaging the analog output signal from the strain-gage load link over 1-sec intervals.

Eighteen parachute deployments were made at nominal Mach numbers of 0.5, 2.0, 2.2, and 2.5 at a nominal free-stream dynamic pressure of 120 psfa. One of the quarter-scale parachute configurations was investigated at M_∞ = 0.5 over a dynamic pressure range from 52 to 202 psfa. On three occasions with the parachute deployed, the Mach number was changed from 2.0 to 2.2. The centerbody was maintained at zero angle of attack for the entire test. A complete summary of the test conditions is presented in Table I.

The drag data obtained during this test were reduced to a parachute drag coefficient. The accuracy of the full-scale and quarter-scale parachute drag force, as determined from calibration of the respective load links, was $F_D = \pm 11.40$ and ± 0.92 lb, respectively.

SECTION IV
RESULTS AND DISCUSSION

4.1 DEPLOYMENT LOADS

Deployments of fabric-type, trailing aerodynamic decelerators generally create two forces known as "snatch force" and "opening shock force." For wind tunnel testing of parachutes, the snatch force is defined as that force imposed on the centerbody by the parachute to decelerate the mass of the parachute from its velocity at line extension to zero velocity relative to the centerbody. The snatch force is followed closely by the opening shock force, which is defined as that force imposed on the centerbody by the inflation of the parachute canopy at full line extension.

For the full-scale and quarter-scale parachutes investigated, the snatch and opening shock forces were found to vary considerably during each deployment since they are a function of the parachute packing procedure. The snatch and opening shock forces for the full-scale and quarter-scale parachutes varied between 700 and 2300 lb and 85 and 255 lb, respectively. Two typical parachute deployment-time histories are shown in Fig. 8; one shows the snatch force equal to the opening shock force, and one shows the snatch force less than the opening shock force.

4.2 STEADY-STATE LOADS

As shown in Fig. 9, the drag coefficient of the full-scale and quarter-scale parachutes decreases with increasing supersonic Mach number. Inspection of the drag coefficient variation with Mach number also shows that the drag coefficient at $M_\infty = 0.5$ is larger than the drag coefficient of the same parachute configuration at supersonic Mach numbers. The variation of drag coefficient with subsonic Mach numbers was not investigated; however, the drag coefficient of hemisflo parachutes, as indicated in Ref. 2, remains essentially constant over the subsonic Mach number range. The data, as indicated in Ref. 2, also substantiate the variation of drag coefficient with supersonic Mach number as obtained during this test.

The drag coefficient of the full-scale and quarter-scale parachutes at $M_\infty = 0.5$ decreases as the canopy porosity increases. Increasing the porosity by 40 percent decreased the drag coefficient of the full-scale and quarter-scale parachutes 14.4 and 13 percent, respectively.

At a given supersonic Mach number, the drag coefficient of the full-scale parachutes decreases as the canopy porosity increases, except at M = 2.2 where the drag coefficient of the 18-percent porosity parachute is greater than that of the 15-percent porosity parachute. The drag coefficient of the quarter-scale parachutes is not proportional to canopy porosity at a given supersonic Mach number.

4.3 SCALE EFFECTS

Both the full-scale and quarter-scale parachutes were investigated at equal unit Reynolds number for a given Mach number. To determine if there were an effect of Reynolds number on drag coefficient, a quarter-scale parachute was tested at $M_\infty = 0.5$ over a Reynolds number range. As shown in Fig. 10, the drag coefficient is invariant with Reynolds number. The effect of Reynolds number on drag coefficient at a supersonic Mach number was not investigated.

Since the drag coefficient is independent of Reynolds number at $M_\infty = 0.5$, the drag coefficient of the full-scale parachute should be equal to the drag coefficient of the quarter-scale parachute. However, scaling of parachutes is not possible with current knowledge of fabrics and fabrication techniques. As shown in Fig. 11, the ratio of the drag coefficient of the full-scale parachute to the drag coefficient of the quarter-scale parachute is greater than unity for parachutes of equal porosity over the Mach number range investigated. Also indicated in Fig. 11, the magnitude of the ratio varies with Mach number. As the supersonic Mach number increases, the ratio decreases for the 18- and 21-percent porosity parachutes and increases for the 15-percent porosity parachutes. The closest drag coefficient agreement between a full-scale and a quarter-scale parachute occurred with the 21-percent porosity, full-scale parachute and the 18-percent porosity, quarter-scale parachute over the Mach number range investigated. The ratio increases from 1.042 at $M_\infty = 0.5$ to 1.100 at $M_\infty = 2.5$.

4.4 INFLATION AND STABILITY CHARACTERISTICS

Photographic coverage obtained by movie cameras permitted the determination of parachute inflation characteristics. Visual analysis of the motion pictures indicated that both the full-scale and quarter-scale parachute models exhibited full canopy inflation at all test conditions.

The behavior of a parachute moving through the air is governed by characteristics which, in airplane design, are called stability characteristics. Certain characteristic parameters have been established which, when known, allow the prediction of stability for specific airplanes. However, published data indicate only limited success in establishing similar parameters for parachutes. The parachute stability characteristics as discussed in this report pertain to the motion of the canopy in a plane perpendicular to the centerline of the centerbody. The motion was defined in terms of average oscillation angle and oscillation frequency about the riser line to centerbody attachment point and was evaluated from motion pictures taken during the test. The reference parachute was considered to be a parachute which has no oscillation about the riser line attachment point to disturb the parachute from its equilibrium position. A tabulation of the stability characteristics for the full-scale and quarter-scale parachutes is presented in Table I. In general, the oscillation angles of the full-scale parachutes are larger than those of the quarter-scale parachutes. However, the difference in magnitude between the oscillation angle of the full-scale and quarter-scale parachutes would have diminished if the riser line length of the quarter-scale parachutes had been to scale. The oscillation angle of the full-scale parachutes varied between 0 and ±9.5 deg, whereas the oscillation angle of the quarter-scale parachutes varied between 0 and ±4.5 deg. The oscillation frequency of the full-scale and quarter-scale parachutes varied between 0 and 2.5 cps and 0 and 3.5 cps, respectively. The effect of canopy porosity on oscillation angle and oscillation frequency was not clearly defined during the test. However, at $M_\infty = 2.5$, the oscillation angle of the full-scale and quarter-scale parachutes increases as the canopy porosity increases. The oscillation angle of the 21-percent canopy porosity, quarter-scale parachute increases from 0 to ±2.0 deg as free-stream dynamic pressure increases from 51.9 to 202.5 psfa.

SECTION V
SUMMARY OF RESULTS

Drag, stability, and inflation characteristics were obtained for proposed stabilization parachute models for the F-111 Crew Module at Mach numbers of 0.5, 2.0, 2.2, and 2.5. A summary of the results of tests on the full-scale and quarter-scale models utilizing the same riser line length is as follows:

1. The drag coefficient of the full-scale and quarter-scale parachutes decreases as the supersonic Mach number increases,

2. The drag coefficient of a full-scale parachute is larger than the drag coefficient of a similar quarter-scale parachute,

3. For a given Mach number, the drag coefficient of the full-scale parachutes decreases as canopy geometric porosity increases,

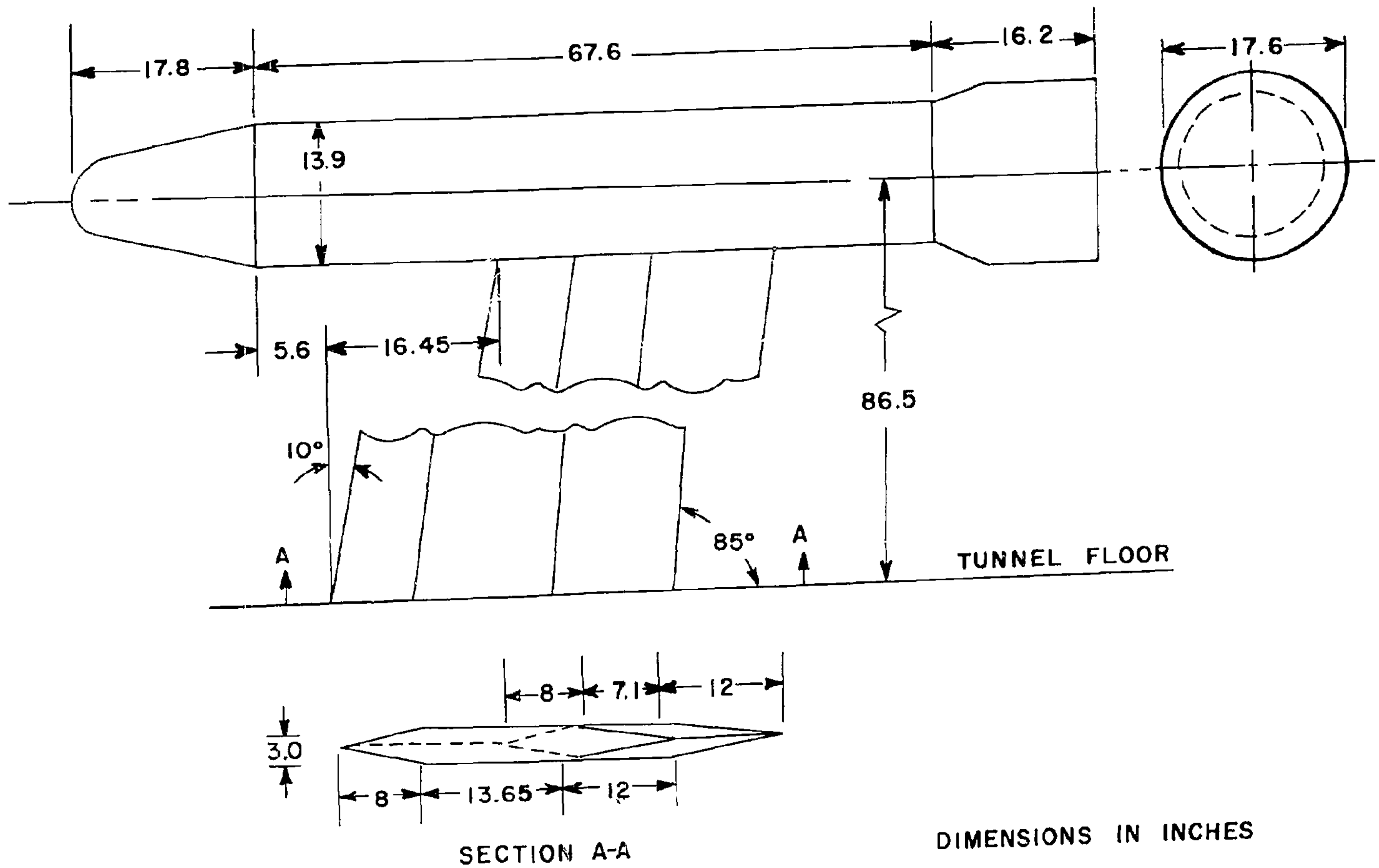
4. The stability of the quarter-scale parachutes is better than the stability of the full-scale parachutes, and

5. The full-scale and quarter-scale parachutes exhibited full canopy inflation throughout the Mach number range investigated.

REFERENCES

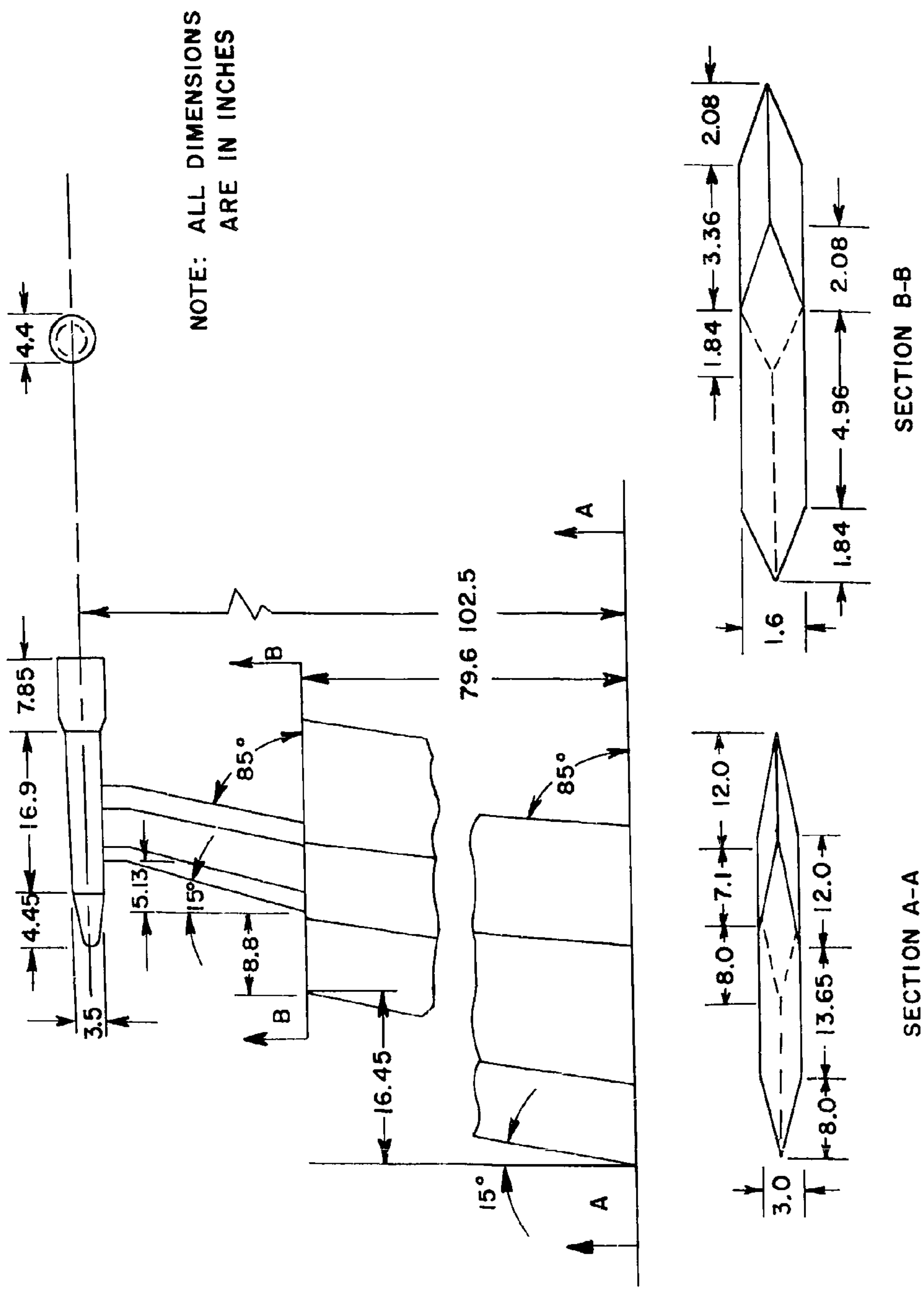
1. Test Facilities Handbook, (5th Edition). "Propulsion Wind Tunnel Facility, Vol. 3." Arnold Engineering Development Center, July 1963.

2. "Performance of and Design Criteria for Deployable Aerodynamic Decelerators." ASD-TR-61-579, Wright-Patterson Air Force Base, Ohio, December 1963.



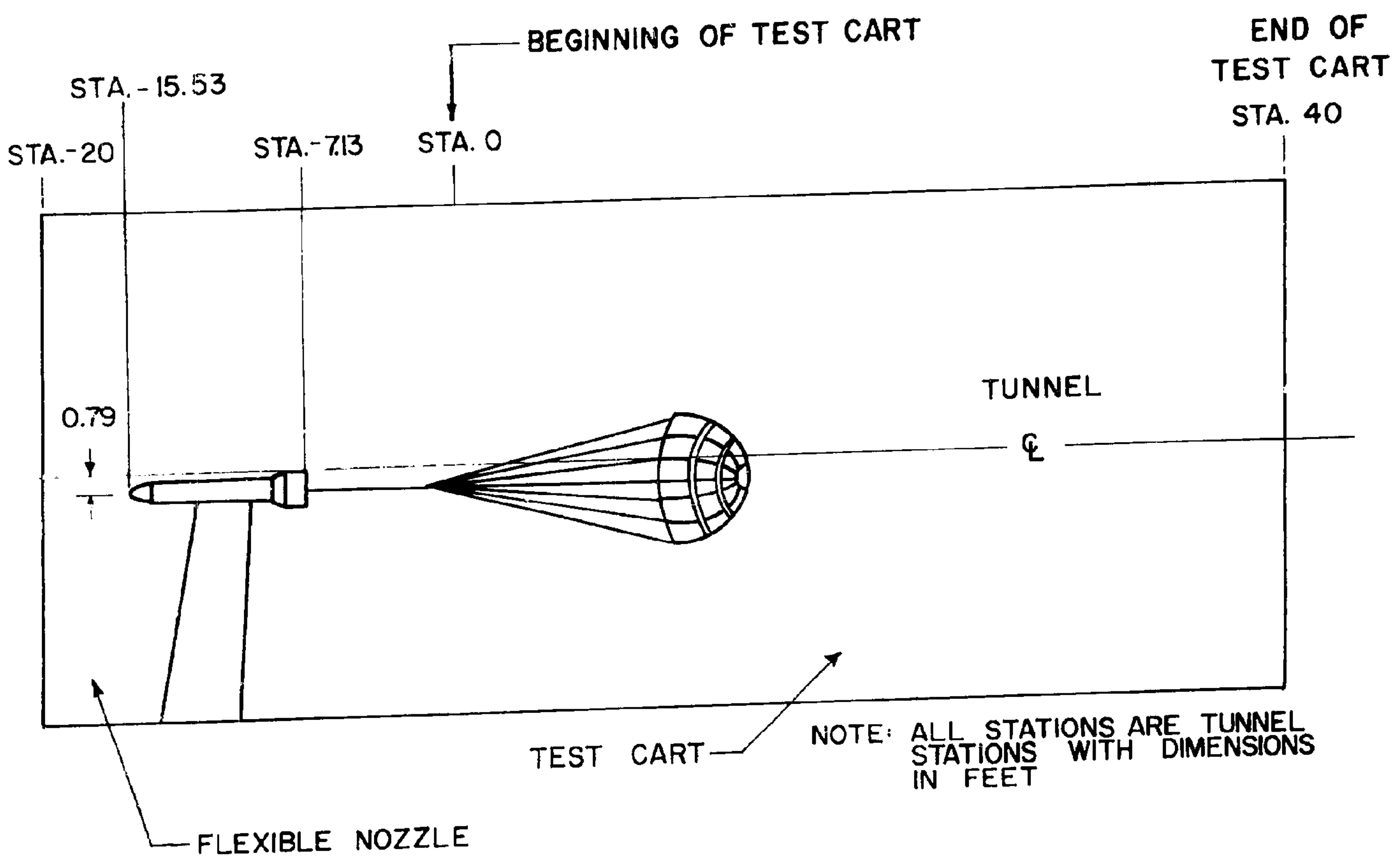
a. Full-Scale Model

Fig. 1 Model Centerbody Dimensions



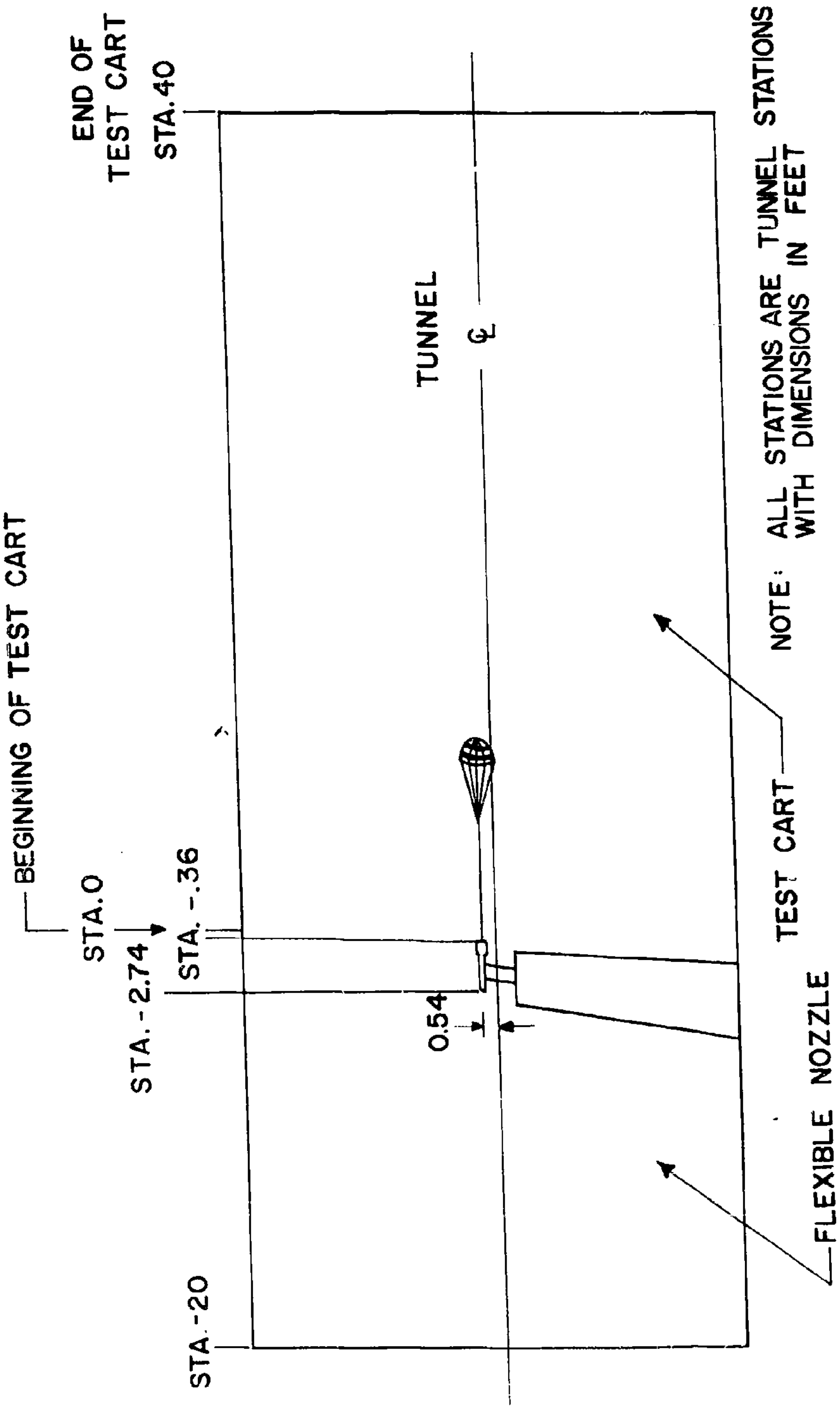
b. Quarter-Scale Model

Fig. 1 Concluded



a. Full-Scale Model

Fig. 2 Location of Model Centerbody in Test Section



b. Quarter-Scale Model

Fig. 2 Concluded

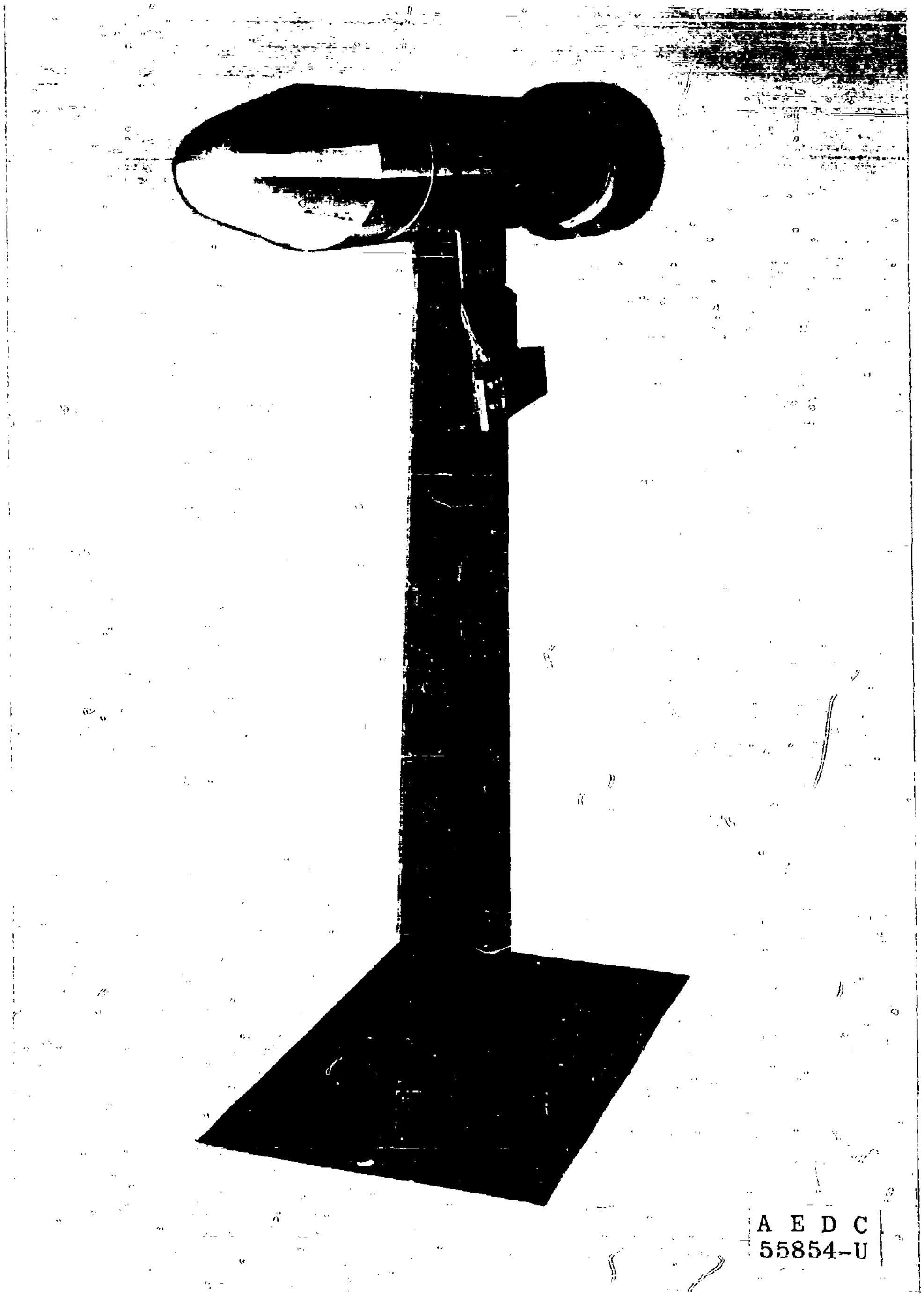
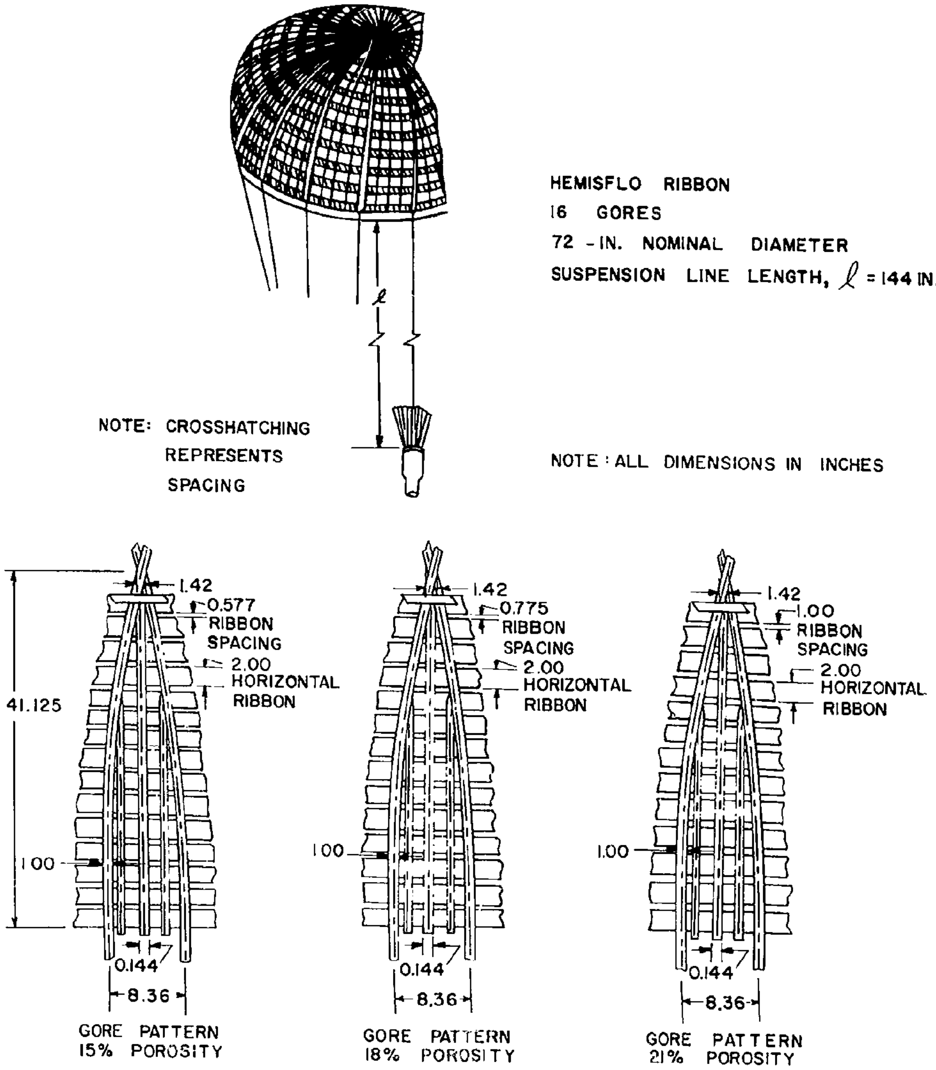


Fig. 3 Installation of Full-Scale Model Centerbody in Test Section

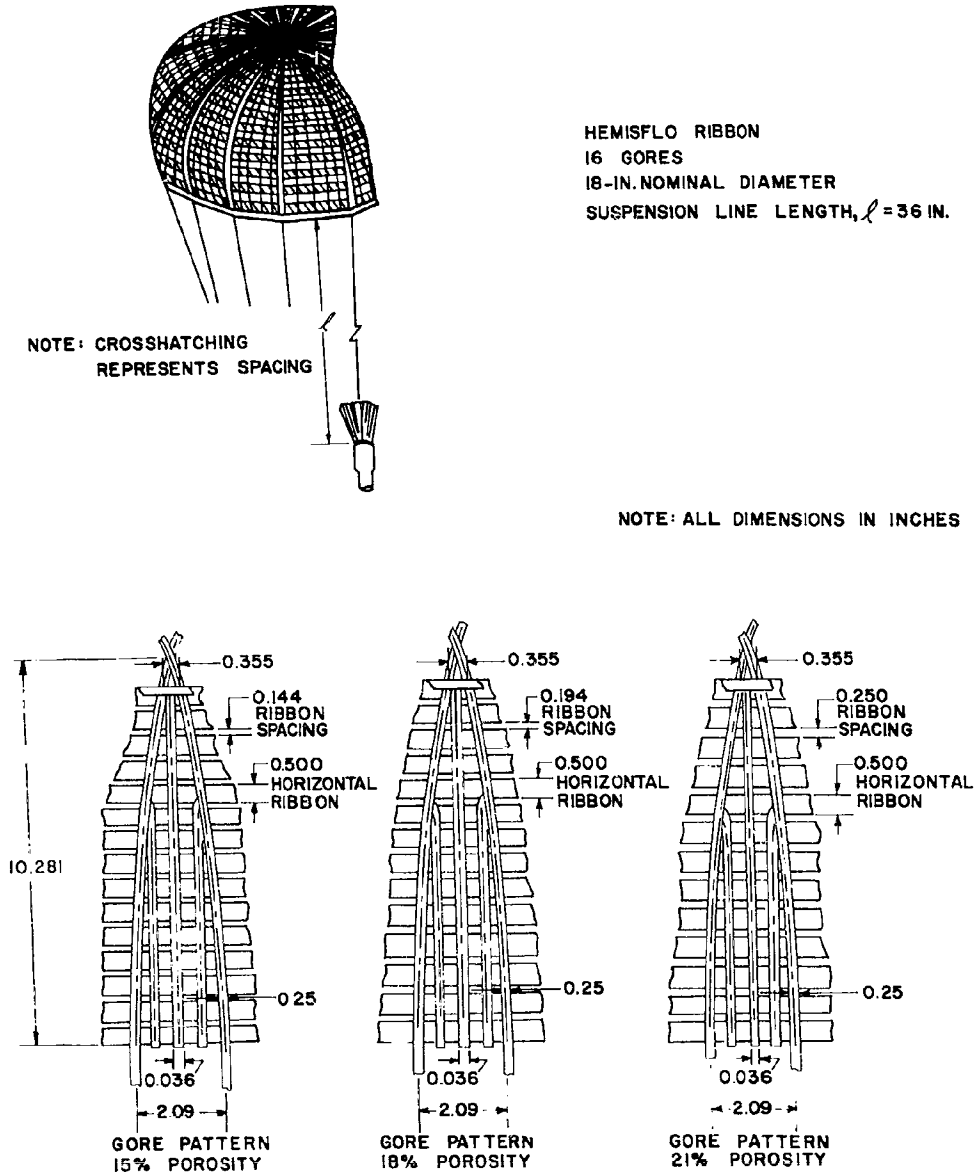
Fig. 4 Installation of Quarter-Scale Model Centerbody with Deployed Stabilization Parachute in Test Section

Fig. 5 Three-Quarter Rear View of Full-Scale Model Centerbody



a. Full-Scale Parachutes

Fig. 6 Hemisflo Parachute Details



b. Quarter-Scale Parachutes

Fig. 6 Concluded

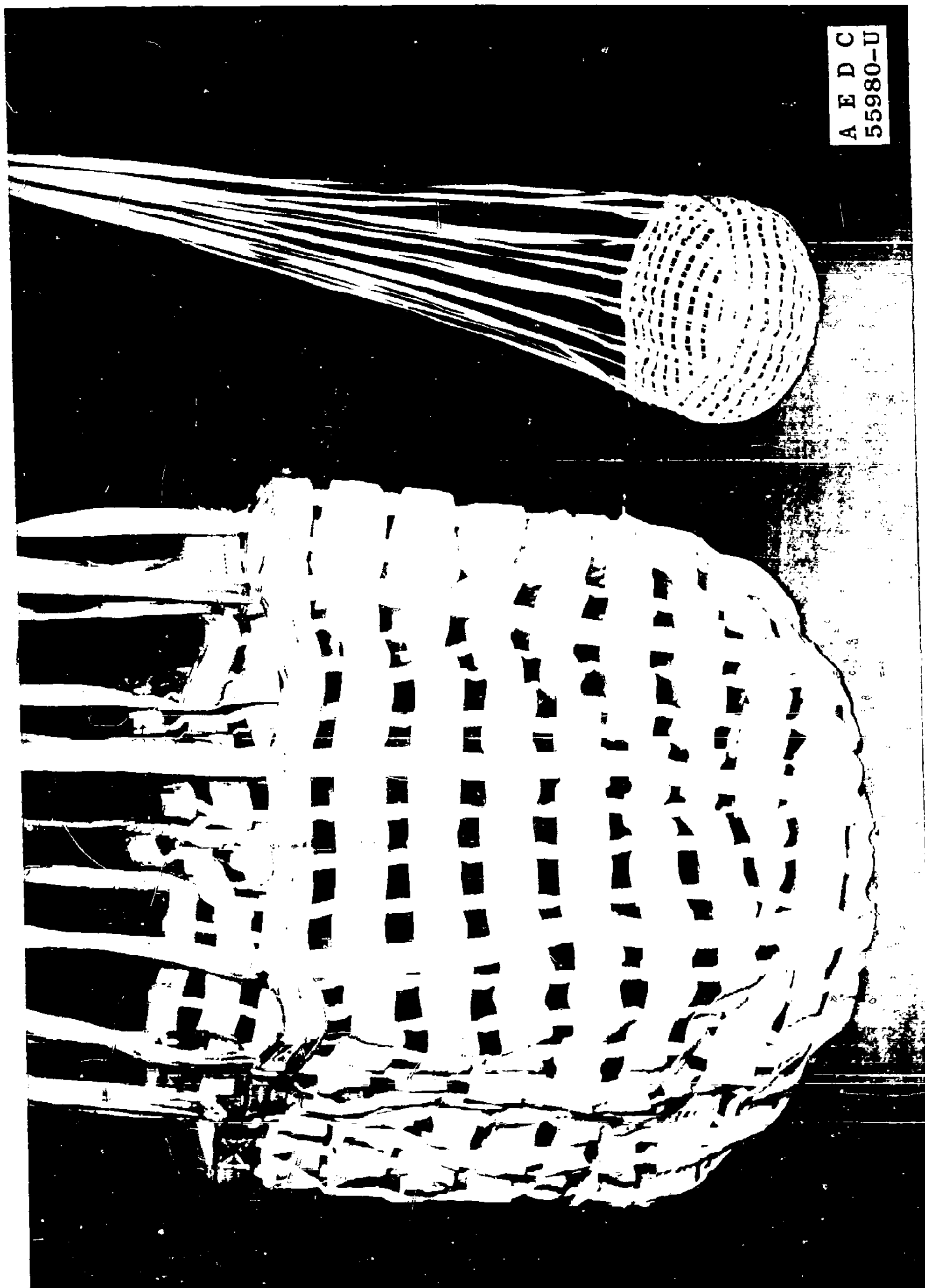


Fig. 7 Full-Scale and Quarter-Scale Hemisflo Parachutes

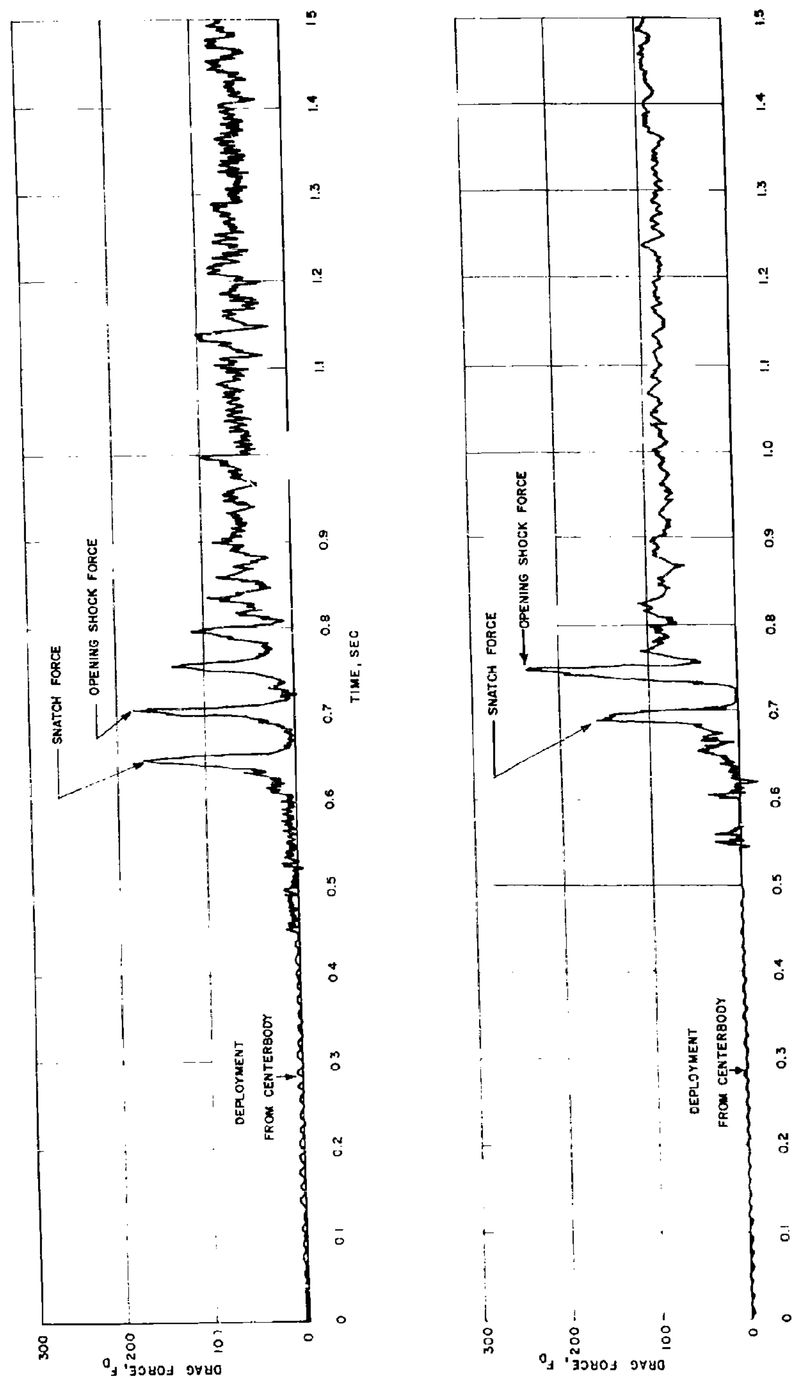


Fig. 8 Typical Hemisflo Parachute Deployment Characteristics

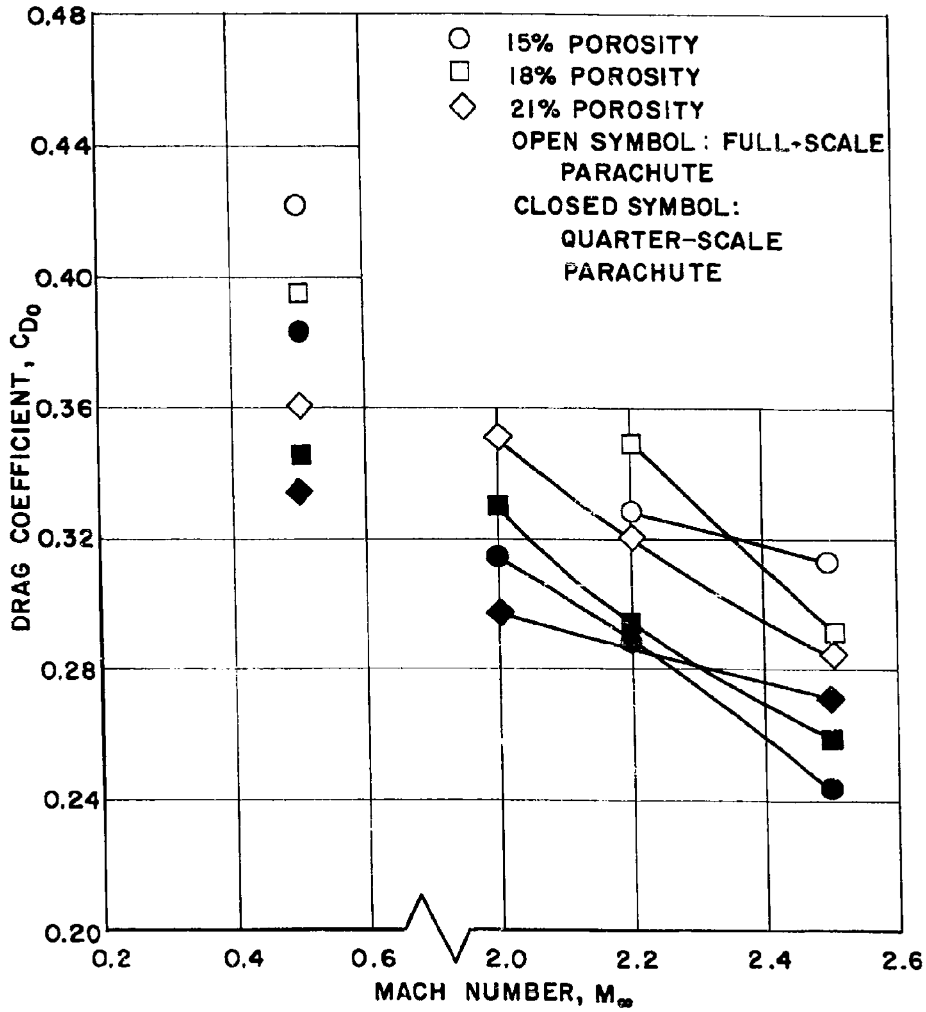


Fig. 9 Variation of Drag Coefficient with Mach Number

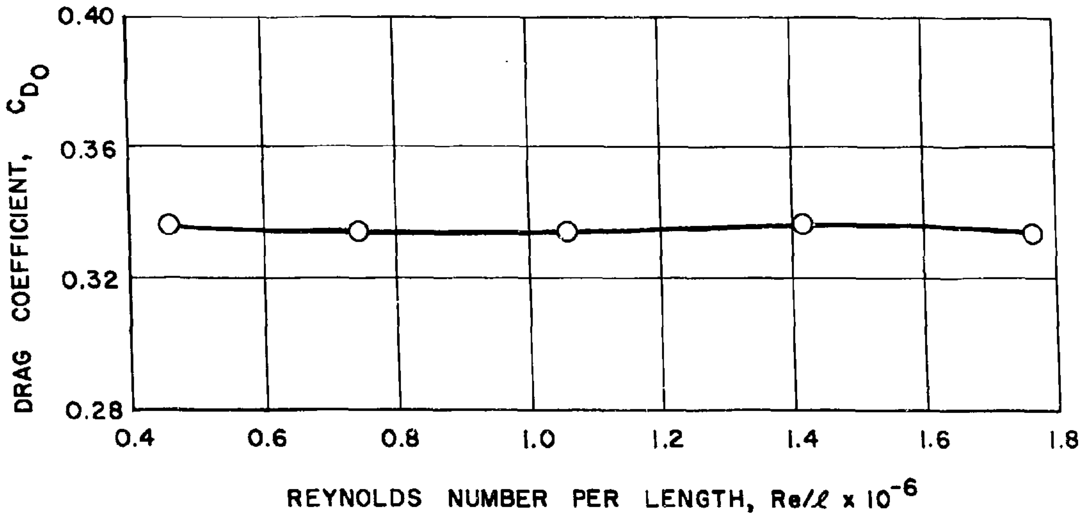


Fig. 10 Variation of Drag Coefficient with Unit Reynolds Number, $M_\infty = 0.5$, Quarter-Scale Parachute, 21-percent Porosity

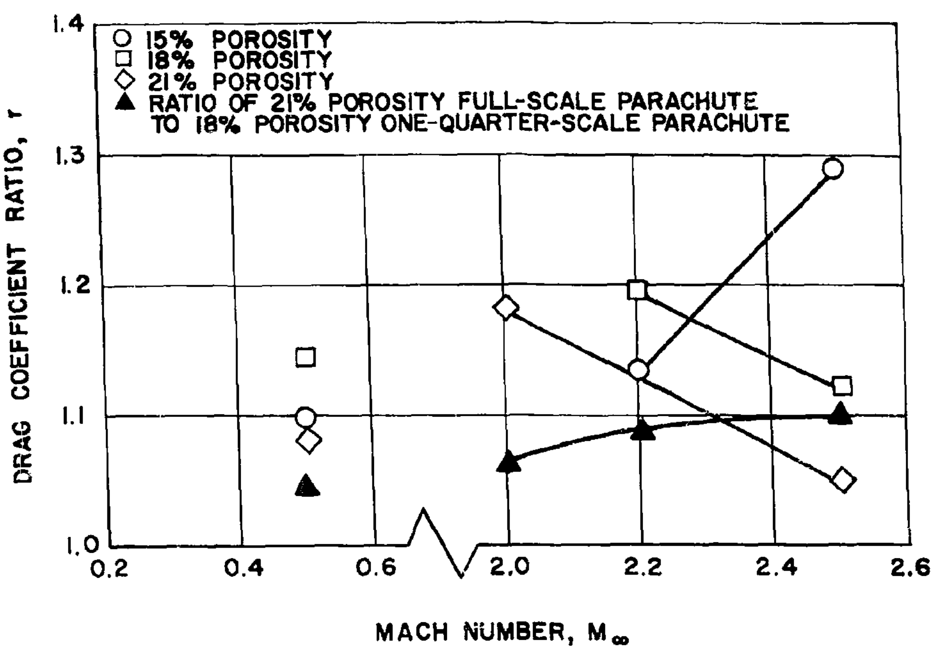


Fig. 11 Parachute Scaling Effects

TABLE I
SUMMARY OF TEST CONDITIONS AND RESULTS

CONFIGURATION	M_∞	q_∞ (psfa)	PARACHUTE NOMINAL DIAMETER (ft)	CANOPY GEOMETRIC POROSITY (%)	C_{D_o}	PARACHUTE STABILITY CHARATERISTICS: AVERAGE ANGLE OF OSCILLATION ABOUT BASE ATTACHMENT POINT (deg)	PARACHUTE STABILITY CHARATERISTICS: AVERAGE FREQUENCY OF OSCILLATION ABOUT BASE ATTACHMENT POINT (CPS)
4	0.500	120.6	6.0	15	0.4220	0	0
5	0.500	120.0	6.0	18	0.3954	0	0
6	0.496	118.5	6.0	21	0.3609	±1.5	2.5
2	1.996	120.4	6.0	21	0.3505	±9.5	2.5
19	2.196	120.9	6.0	21	0.3188	0	0
1	2.197	120.2	6.0	15	0.3280	±9.5	2.0
3	2.200	120.5	6.0	18	0.3491	±6.5	2.0
7	2.495	120.4	6.0	15	0.3130	±7.5	1.5
8	2.503	119.8	6.0	18	0.2908	±8.0	2.5
9	2.497	120.2	6.0	21	0.2851	±8.5	2.5
13	0.499	119.8	1.5	15	0.3839	±1.5	2.0
14	0.498	119.4	1.5	18	0.3456	±2.0	2.0
15	0.501	120.7	1.5	21	0.3348	±1.5	2.5
15	0.499	84.6	1.5	21	0.3346	±1.0	1.5
15	0.499	51.9	1.5	21	0.3378	0	0
15	0.499	161.2	1.5	21	0.3371	±1.5	2.5
15	0.499	202.5	1.5	21	0.3342	±2.0	2.0
10	1.995	120.4	1.5	15	0.3154	±1.5	3.5
20	2.195	120.5	1.5	15	0.2890	±1.0	2.5
11	1.999	120.2	1.5	18	0.3306	±1.5	1.5
21	2.199	120.5	1.5	18	0.2926	±3.5	1.5
12	1.999	119.5	1.5	21	0.2966	±1.5	3.5
16	2.492	120.8	1.5	15	0.2430	±1.0	3.0
17	2.492	121.0	1.5	18	0.2591	±1.5	2.5
18	2.489	121.0	1.5	21	0.2717	±4.5	3.5

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13. ABSTRACT

A test was conducted in the Propulsion Wind Tunnel, Supersonic (16S) to obtain drag, stability, and inflation characteristics of full-scale and quarter-scale models of proposed stabilization parachute configurations for the F-111 airplane crew module. The parachutes were fabric, ribbon-type models of the hemisflo family of parachutes with geometric porosities of the canopy of 15, 18, and 21 percent. The parachute characteristics were investigated at nominal Mach numbers of 0.5, 2.0, 2.2, and 2.5 at a nominal free-stream dynamic pressure of 120 psfa. Test results indicate that the drag coefficient of the full-scale and quarter-scale parachutes decreases as supersonic Mach number increases and that the stability of a quarter-scale parachute is better than the stability of a full-scale parachute for the same riser line length.

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	ROLE	WT	ROLE	WT	ROLE	WT
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hemisflo						
full-scale						
quarter-scale						
drag						
stability						
inflation						
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There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

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